Liquid-Metal MHD Power Conversion

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A liquid-metal magnetohydrodynamic (MHD) power converter has been successfully operated with the generation of ac electrical power. Gaseous nitrogen is used to produce the closed-cycle flow of the liquid-metal (NaK) working fluid through the MHD generator where the fluid kinetic energy is converted to electrical energy. In this article the operational characteristics of the converter are given and the results of the current series of tests are discussed.

Introduction

Liquid-metal magnetohydrodynamic (MHD) power conversion (Reference 1) is being investigated as a power source for nuclear-electric propulsion. A liquid-metal MHD system has no moving mechanical parts and operates at heat-source-temperatures between 1200 and 1400 K. Thus, the system has the potential of high reliability and long lifetime with the use of readily available containment materials such as Nb–1%Zr.

NaK–Nitrogen Converter

The NaK–nitrogen test system to evaluate the electrical and hydraulic characteristics of a liquid-metal MHD converter has been successfully operated with the generation of ac electrical power. An output of 1.0 kW at 120 V and 350 Hz has been obtained in early tests with low generator currents.

The converter is shown in Figure 1. Runs are started by feeding nitrogen at 2.5 kg/s to the 1600-orifice NaK–nitrogen mixer. NaK is then injected from a nitrogen-pressurized start-tank at 75 N/cm^2 and 40 kg/s. NaK is also supplied to the mixer through a pressure regulator at 5 kg/s from a 650-kg NaK supply under 150-N/cm^2 nitrogen pressure. The added NaK increases the circulating liquid flow rate and causes the nozzle inlet pressure to increase. When the pressure reaches the value for which the regulator is set, the regulator throttles the flow back to an

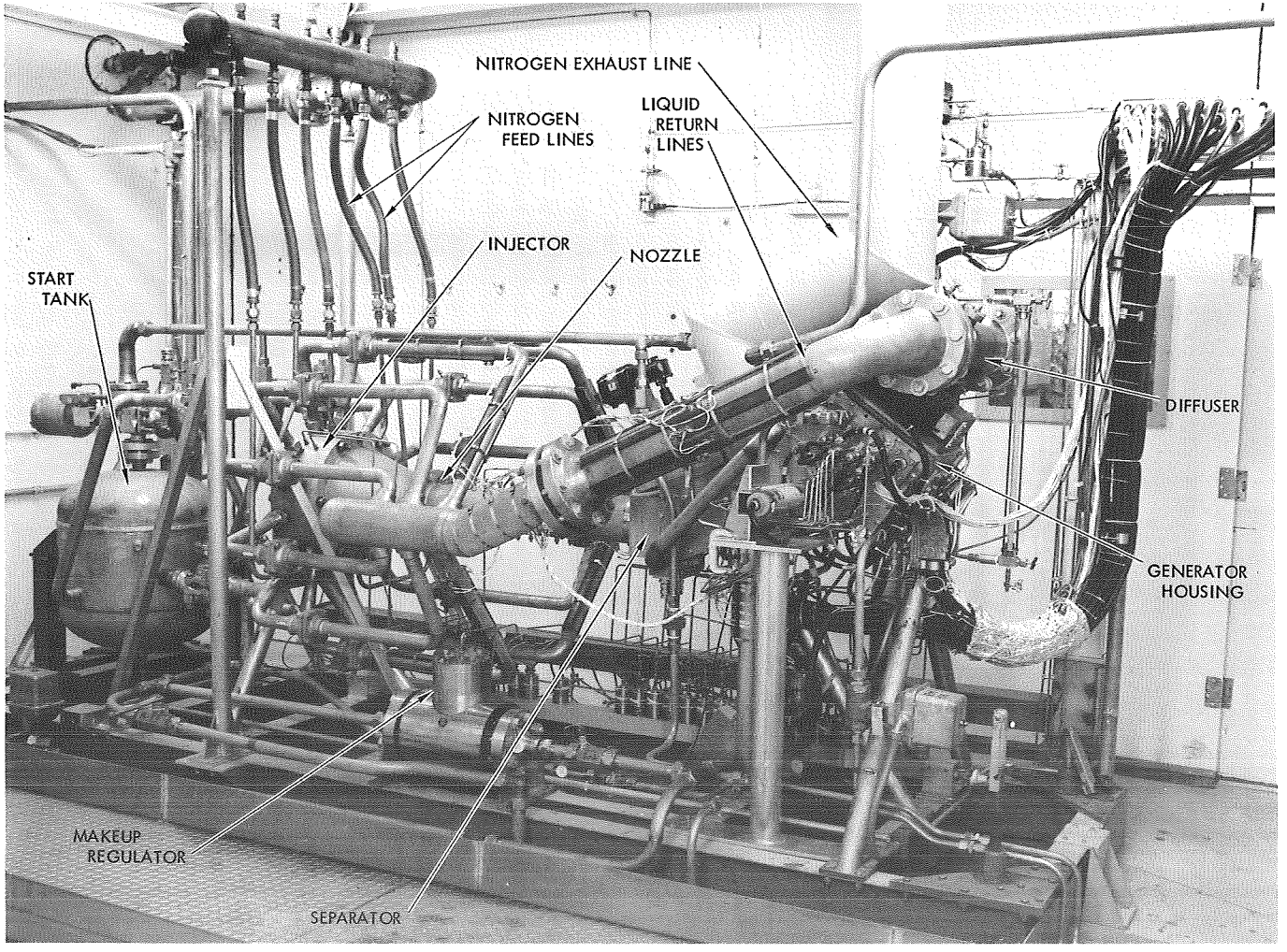

Figure 1. NaK–N_2 liquid-metal MHD system

amount equal to that lost with the nitrogen and collected in a mist separator. The main problem encountered in startup has been establishing reasonably uniform pressure of the Mach 2 to 4 NaK–nitrogen flow in the generator channel. If the nitrogen flow to the nozzle is too high, a shock forms in the generator channel upstream of the diffuser, and pressures can reach 140 N/cm^2 in the downstream part of the generator. If the nitrogen flow is too low, a shock forms at the capture slot leading to the generator, reducing the fluid power available and increasing the NaK flow to the mist separator.

After startup, which requires about 20 s, adjustments can be made in the nozzle inlet pressure and in the nitrogen flow rate to reach various flow conditions for generator operation. A nozzle inlet pressure of 103 N/cm^2 and nitrogen flow rates between 1.8 and 2.5 kg/s are currently being used. The NaK flow rates range from 47 to 62 kg/s.

The ac induction generator is then started by bringing up the alternator field. The six traveling-wave phases and the downstream compensating-pole phase are connected to capacitors and resistors of the desired values. The upstream compensating-pole phase is connected across the alternator since this phase requires power input; capacitance is still provided for the reactive power requirement. (The alternator can be replaced by transformer coupling to the other phases, but the present arrangement provides more positive control of generator current.) The currents in the seven self-excited phases rise in proportion to the current in the alternator-driven phase. When the approximate desired current levels are reached, the final trimming of current amplitudes and phase angles is done by adjusting variable transformers connecting the capacitors and resistors to the generator. After the generator currents are satisfactorily adjusted, the phase power outputs (or input, in the case of the upstream, alternator-driven phase) are recorded, together with currents, voltages, phase angles, and flow parameters.

The adjustment process has been found to be difficult and time-consuming. Changing the capacitance or resistance on one phase not only changes the amplitude and phase angle of the current in that phase, but also affects the currents in all of the other phases. A procedure is currently being developed to calculate the required capacitance and resistance changes in each of the eight phases to correct the current amplitudes and phase angles.

Current Test Series

The current test series has consisted of 14 NaK runs of 5- to 10-min duration with generator operation. The generator has operated qualitatively as expected, with power output from seven phases and input to one, but the internal power output from the NaK to the coils has been only about 65% of that predicted. When the winding loss is subtracted,

the net output is only a fraction of the predicted value. The net output was 300 W at 15-A current in the traveling-wave phases. The predicted power output was 1150 W. The most likely explanation is low fluid conductivity as a result of the flow expansion in the generator channel. The predicted power was based on the assumption that the flow in the generator channel would be at the same pressure (25–70 N/cm^2) and same gas–liquid volume ratio (0.3–0.6) as the flow leaving the upstream diffuser. In the NaK runs the generator channel pressure was only 10 N/cm^2 and if, in addition, the flow expanded to uniformly fill the channel, then the volume ratio was in the range 1.5–2.0, which would reduce the conductivity sufficiently to account for the low output power.

Empty channel tests conducted prior to the current test series indicated that the unexpectedly high stator losses in the generator are due to eddy currents in the coils caused by the field perpendicular to the flat strip coil turns.

During the NaK tests an insulation failure occurred in one of the coils as the generator voltage was being raised above the 90-V level. The failure had the effect of shorting nine turns on the upstream C-phase coil which increased the coil losses by 400 W and canceled the net output power.

The shorted turns have been removed from the coil. In order to maintain constant ampere-turns in both C-phase coils, the 31-turn coil is excited by the 40-turn coil through a current transformer.

Testing has resumed, and an output of 1.0 kW has been obtained.

Reference

1. Elliott, D. G., Hays, L. G., and Cerini, D. J., "Liquid-Metal MHD Power Conversion," in *Supporting Research and Advanced Development*, Space Programs Summary 37-51, Vol. III, pp. 120–124. Jet Propulsion Laboratory, Pasadena, Calif., June 30, 1968.